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Dynamic modelling of the secondary settler of a wastewater treatment via activated sludge to low-load

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Abstract

The aim of this study is to apply a mathematical treatment to a case study that concerns the biological wastewater treatment. Its objective was to develop a model that aims at predicting the conditions that would lead to an outlet clear water out from a secondary settler. It deals with a wastewater treatment process which consists of the separation by decantation of an activated sludge coming out of an aerobic low-load reactor.

First, it was necessary to estimate the pollution parameters namely: the total suspended solid (TSS), the chemical oxygen demand (COD), the biological oxygen demand (BOD_5) and ammonia content (NH_3-N).

Secondly a mathematical model for the secondary settler was developed. The monitoring of the wastewater treatment plant as well as the knowledge of the experimental parameters such as the sludge blanket height, the TSS, and decantation time enabled us to develop the mathematical model. The advantage of this model is that it would allow a better process control.

Keywords: Wastewater, activated sludge, secondary settler, sedimentation, mathematical modelling ;

1. Introduction

The performance of wastewater treatment plants based on the activated sludge process depends essentially on the behaviour of the secondary sedimentation tanks [1]. The characterization of the sedimentation tank is less developed compared to the aeration tank [2]. This is partly due to the diversity and complexity of the mechanisms involved in the separation of liquid and solid phases [3-4].

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Nomenclature

A	clarifier surface area, m^2
BOD_5	biochemical oxygen demand in five days, Kg/m^3
COD	chemical oxygen demand, Kg/m^3
F_h	downward bulk flux, Kg/m^2 h
F_s	gravity settling flux, Kg/m^2 h
$NH_{3\text{-}}N$	ammonia, Kg/m^3
Q_r	recirculation flow rate, m^3/h
Q_f	feed volumetric flow rate, m^3/h
Q_s	outward volumetric flow rate, m^3/h
SVI	sludge volume index, m^3/Kg
TSS	total suspended solids, Kg/m^3
$V_o, V_o^{'}$	maximum theoretical settling velocity, m/h
V_s	gravity-settling velocity, m/h
X	total suspended solids concentration, Kg/m^3
z	sludge blanket height, m

The design and operation of secondary settlers is commonly based on the solid flux theory using the state point analysis [5-6-7]. Regardless of the model chosen, measurements of settling velocities determined using zone settling tests are commonly used for calibration [8].
Batch settling curves have also been applied in order to include compression settling, using the Vesilind Model [5], and also for the different regimes separation following the Vesilind form [8-9].

Therefore this study focused on the characterization of the movement of the sludge blanket in the secondary settler using the solid flux theory and the velocity settling. This allowed us develop a model based on a thorough experimental study carried out in situ and the application of on-line data which are the mass load flow, transfer concentration, and influent characteristic. On the other hand introducing corrections values of the sludge volume index (SVI) allowed the model to reduce sludge height variations and thus increase the solid/liquid separation.

2. Materials and methods

2.1. Description of the WWTP

The wastewater treatment plant (WWTP) in this study is located in the city of Sétif-Algeria. The plant is operated by the National Algerian Wastewater Board (NAWWB). It is a 330.000 P.E. (influent 66000 $m^3.day^{-1}$). The plant consists of gridirons, primary clarifiers, and oxidation reactors.

Wastewater is first introduced and mixed in the aeration reactor by a turbine. Then, the mixed liquor is allowed to settle in the settling period. The activated sludge is settled in secondary settlers. At the end of each cycle of the excess mixed liquor is discharged from the reactor. After settling, the effluent is discharged into a nearby river.

Municipal wastewater plant characteristics, expressed in terms of Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS), are typical of those of low-to-medium load. Treatment efficiencies in terms of BOD_5, DCO, TSS, and ammonia (NH_3-N) exceeded 97%, 95%, 99.5% and 78%, respectively.

2.2. Experimental procedure

A secondary clarifier helps to separate the solids from the liquid phase of the mixed liquor, and remove settled solids from the bottom of the settler. In a wastewater treatment plant, the secondary settler is the fundamental work that ensures the gravity separation of sludge and treated water discharged into the receiving environment. The good knowledge of the process is a prerequisite for any attempt develop a mathematical model. The proper functioning of this settler implies a good design and a rational management of sludge production and control of its settleability.

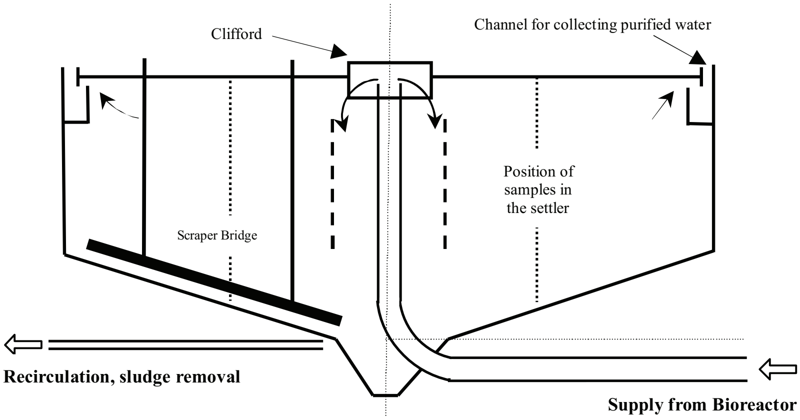

Fig. 1. Geometry of the secondary settler of the WWTP in Setif

Figure1 is a scale representation of the settling tank of the wastewater treatment plant in Setif. It is a cylindrical-conical clarifier with a diameter of 46 m, and is 7.20 m deep. This develops an area of 1661 m^2. The height of the cylinder is 4 m and that of the conical part is 3 m with a bridge and a scraper or a large Clifford (skirt distribution). The figure shows the position where the samples were taken.

2.3. Verification of the horizontality of the sludge blanket

A manual exploration of the surface of the sludge blanket was carried out using a white disk having a diameter of 20 cm attached in its center by means of a cable 5 m long and 0.1 m graduated.

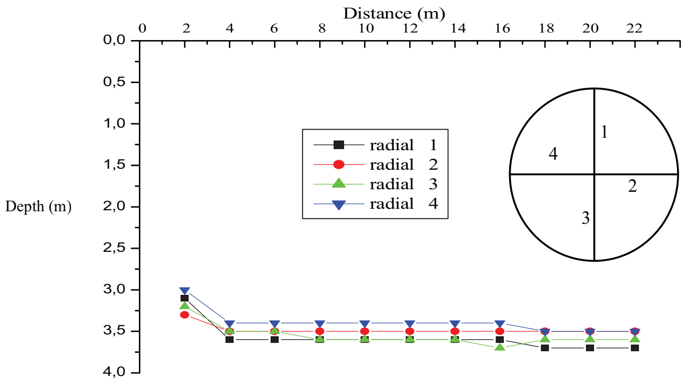

Fig. 2. Manual measurement of the depth of sludge blanket

Measurements were made on four perpendicular radials (Fig. 2) within a regular interval of time of half an hour. The sludge blanket is located at a depth below the base of Clifford.

Apart from a turbulent area near the Clifford (skirt distribution), the measurements show a good horizontality (a precision of ± 50 centimeters) of the sludge blanket throughout the entire surface of the decanter.

From this figure one can note the followings:

- The feeder layer of the decanter is located at the Clifford.
- The horizontality of the sludge blanket was also observed visually when it approaches the surface of the decanter.
- A one-dimensional model is possible.

These results have also been reported in the literature [10-11].

2.4. Concentration profiles of the sludge

The measurements consist of taking samples from the secondary settler and parallel to the Clifford (see Fig. 3). The samples are taken for two radials.

The sludge concentration is expressed as total suspended solids (TSS) and averaged for each depth. All measurements were taken in dry time (no rainy periods) and without interruption or sludge blanket overflow. The sludge blanket is located at a depth of 3 m.

The transfer concentration from the aerator to the settler is 5.5 Kg/m^3. On the average, the concentration at the Clifford feeding the decanter sludge is only 2.5 Kg/m^3. This concentration is low upon leaving the Clifford. The water in the clarification zone quickly dilutes the sludge [10].

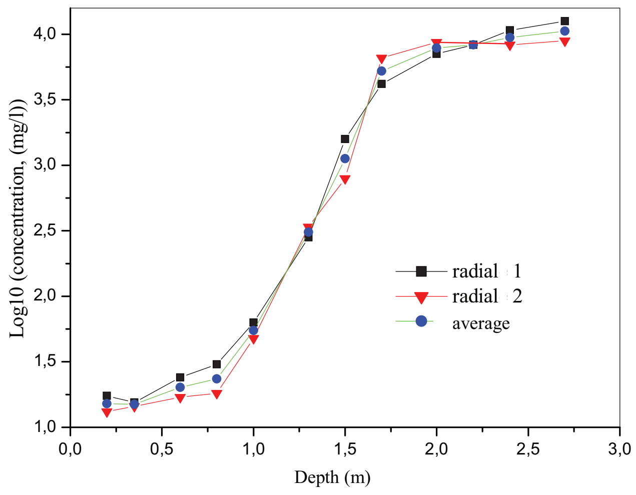

Fig. 3. Measured concentration (TSS) as a function of the depth in the secondary settler

Finally, it is to be noted that the variations in the height of the sludge blanket were taken based on the real operating parameters of the sewage treatment plant of Setif. This is to get an operational model that would be validated through experience.

3. Dynamic modeling of the secondary settler

The proposed model has enabled us to attain a better knowledge of the decantation process of the settling of activated sludge in the secondary settler. In a secondary settler, the existence of an area where settling occurs in mass is a priori not obvious in a conventional operation. Lee [4] clearly distinguishes his work compared to that of Bürger [12] who rather introduce a critical area. According to the classical theory of Marsilli-label [3] and Chancellor [13-14] (originally from the theory of flow) the boundary layer to a separator system is formed in the settling mass. However Bürger [15] and Sin [16] showed that the critical area could also form in the compression zone but Lee [4] states that this area appears only in the compression zone. Nevertheless, the continuous flow of the solid sludge in the feeder layer zone causes a perturbation of the sludge blanket leading to an increase of its height.

3.1. Model overview

Our model is a one dimension model based on the flow theory and without integrating the dispersion. The dispersion (diffusion) between layers is assumed as a plug-type flow.

The assumptions made for this model are the followings:

- This model deliberately neglects sludge growth and assumes a constant mass in the system,
- The sedimentation velocity depends only on the concentration,
- There is a conservation of mass, and biological reactions are neglected,
- The two settler compartments (clarification and thickening) are assumed to be homogeneous.

3.2. Numerical resolution

Sedimentation of solid compounds in the secondary clarifier produces an accumulation of the sludge and becomes more compact at the bottom of the unit. This variation in concentration permits to distinguish two different compartments; the clarification compartment and the thickening compartment. (Fig. 4).

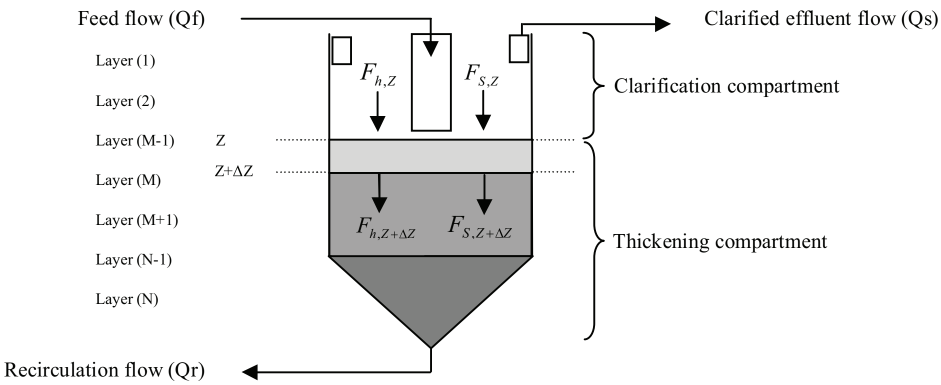

Fig. 4. Mass balance at the thickening zone

The mass balance equation (Fig. 4) is

$$\frac{\partial(X.A.\Delta z)}{\partial t} = F_h(z) - F_h(z+\Delta z) + F_s(z) - F_s(z+\Delta z) \quad (1)$$

The downward bulk flux and gravity settling flux, is defined as

$$F_h = \frac{Q_r}{A} X \qquad \& \qquad F_S = V_S X \quad (2)$$

The equation (1) takes the following form

$$\frac{\partial X}{\partial t} = -\frac{\partial F_h}{\partial Z} - \frac{\partial F_S}{\partial Z} \tag{3}$$

After differentiation of equation (3), we have

$$\frac{\partial X}{\partial t} = -\frac{Q_r}{A}\frac{\partial X}{\partial Z} - \frac{\partial (V_S X)}{\partial Z} \tag{4}$$

We can simulate with equation (4) for the clarification zone (see Fig. 4), we have

$$\frac{\partial X}{\partial t} = -\frac{Q_S}{A}\frac{\partial X}{\partial Z} + \frac{\partial (V_S X)}{\partial Z} \tag{5}$$

For layer (i=1),

$$\frac{dX_1}{dt} = \frac{Q_S(X_2 - X_1) - V_{S,1}X_1 A}{A.\Delta Z} \tag{6}$$

For layers above the feeder layer,

$$\frac{dX_i}{dt} = \frac{Q_S(X_{i+1} - X_i) - V_{S,i-1}X_{i-1}A - V_{s,i}X_i A}{A.\Delta Z} \tag{7}$$

For feed layer,

$$\frac{dX_M}{dt} = \frac{Q_f(X_f - X_M) + V_{S,M-1}X_{M-1}A - V_{S,M}X_M A}{A.\Delta Z} \tag{8}$$

For layers under layer fee,

$$\frac{dX_i}{dt} = \frac{Q_r(X_{i-1} - X_i) + V_{S,i-1}X_{i-1}A - V_{S,i}X_i A}{A.\Delta Z} \tag{9}$$

For bottom layer (i=n),

$$\frac{dX_N}{dt} = \frac{Q_r(X_{N-1} - X_N) + V_{S,N-1}A}{A.\Delta Z} \tag{10}$$

Equation (10) gives the settling dynamic model without a term of dispersion and where (X) is the concentration, (N) is the number of layers and (Z) is the height.
The nonlinear differential equations are solved by the iterative method.

4. Results and discussion

The mathematical equation that describes sedimentation is given by equation (11) which expresses the relationship between sedimentation rate and concentration. Some examples of speed functions are summarized in Table (1). These data were obtained from the wastewater treatment plant of Setif.

Table 1.Experimental data for sludge settling at low load

Parameters	Settleability (ml/l)	TSS (Kg/m^3)	SVI (m^3/Kg)	V_s (m/h)
Undiluted	250	0.90	0.2772	3.75
1st dilution	165	0.56	0.2913	5.85
2nd dilution	98	0.39	0.2483	6.75
3rd dilution	68	0.20	0.3365	9.19

In the classical theory, the settling velocity is estimated from tests on batch settling. In this study, the settling velocity was obtained from the variation of the liquid / solid interface with time.

In the proposed model the velocity law used (equation 11) is based on the Vesilind [17] function which is expressed as follows:

$$V_s = \begin{cases} V_o \; e^{-(0.155+0.0025.SVI)X} & 0 \le X < X_T \qquad \textit{Clarification Compartment} \\ V_o' \; e^{-(0.120+0.0021.SVI)X} & X \ge X_T \qquad \textit{Thickening Compartment} \end{cases} \qquad (11)$$

Where X_T is the sludge concentration at the onset of the thickening compartment. The parameters V_o, V_o' and SVI are regarded as constants that require estimation for the low load case and medium load case respectively and can be obtained by batch settling tests.

4.1. Application of the model to the WWTP of Setif

In this part the measured experimental results will be compared to those predicted by the proposed model taking into account the real operating conditions of the wastewater treatment plant of Setif, which are listed in Table 2.

Table 2. Characteristics of the secondary settler at Setif WWTP

Parameters	Values
A	1661 m^2
Q	100-1320 m^3/h
X_f	1.5-7.0 Kg/m^3

As shown in Fig. 5 (for both low and medium load) the experimental results are in accordance with those predicted by the proposed model at low values of the depth (0.0 - 2.5 m). However at high values of depth (2.5 - 3.5 m), the curve of the variation of concentration with depth for the experimental results is slightly above that of the model. It is interesting to note that the largest differences are situated at the thickening zone. These differences could be attributed to the difficulty in taking samples at a depth of more than 2.5 m.

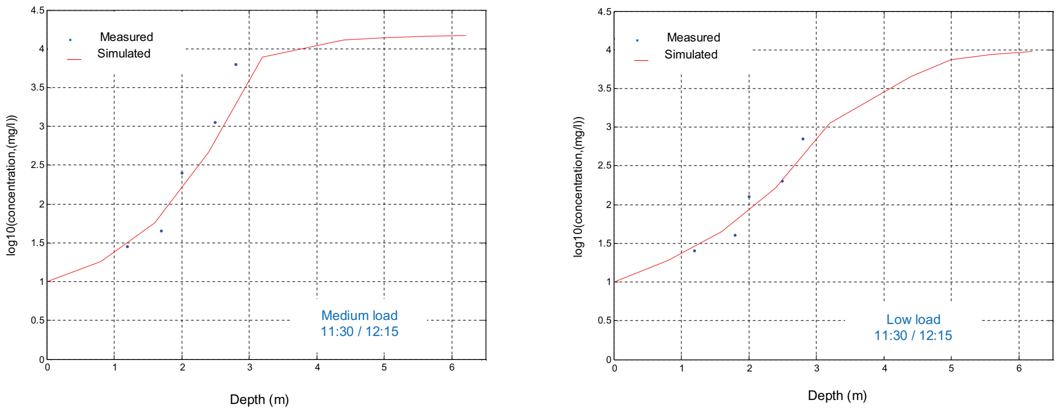

Fig. 5. Sludge concentrations measured and simulated as a function of depth in the secondary settler

4.2. Effect of the number of layers

The effect of the number of layers has been investigated by several authors (Dauphin [10], Lee [4]). The results obtained in this study are presented in Figure 6. It can be seen that the three curves converge rapidly to that predicted by the proposed model if the number of layers chosen is sufficiently small. In other words the lower the number of layers the more the results are in accordance with those predicted by the model. This is perfectly illustrated for the case of 10 layers.

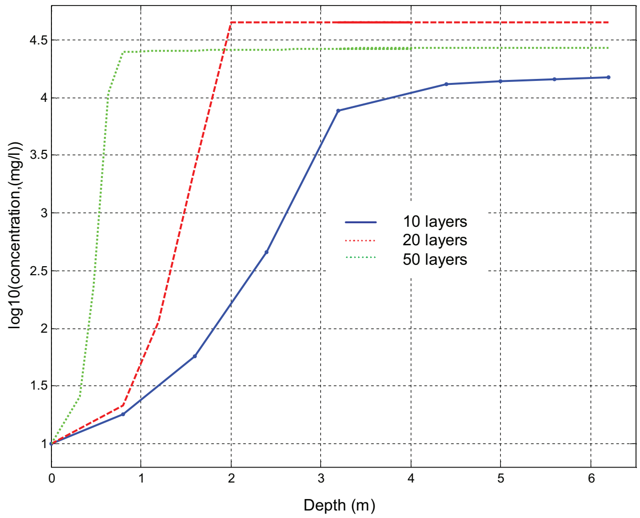

Fig. 6. Effect of the number of layers

5. Conclusion

The aim of this study was to develop a mathematical model for the secondary settler of wastewater treatment.

In this study, the movement of the sludge blanket was characterized using the solid flux theory and the velocity settling.

The model included also the real operating conditions of the wastewater treatment plant of Setif – Algeria. It was found that the experimental results in terms of variations of the sludge concentration with depth were in accordance with that predicted by the model for a depth range of 0.0 and 2.5 m.

Concerning the effect of the number of layers, it was found that the experimental (measured) results fit on those predicted by the model when the number of layers is less than or equal 10.

For a more realistic model, it would be necessary to involve the secondary settler design and understand better the characterisation of the sludge settling.

References

[1] Von Sperling M, Vasconcellos Froes C. M. Determination of the required surface area for activated sludge final clarifiers based on a unified database. *Wat. Res.* 1999; **33**:1884.

[2] Hadj-Sadok M Z, Gouzé J L. Estimation of uncertain models of activated sludge processes with interval observers. *Journal of Process Control* 2001; **11**: 299-310.

[3] Marsilli-Libelli S. Dynamic modelling of sedimentation in the activated sludge. *Civil. Eng. Syst.*1993; **10**, 207-224.

[4] Lee T T, Wang F Y, Newell R B. Distributed parameter approach to the dynamics of complex biological processes. *AIChE Journal* 1999; **45**, 10: 2245-2268.

[5] Vanderhasselt A, Vanrolleghem P A. Estimation of sludge sedimentation parameters from single batch settling curves. *Wat. Res.*2000; **34**, 2: 395.

[6] Ong S L. Effect of measurement error of settling velocity on secondary tank design. *J. Water Pol. Con. Fed* 1992; 104-110.

[7] Daigger G T. Development of refined clarifier operating diagrams using an updated settling characteristics database. *Water Environ. Res.*1995; **67**: 95-100.

[8] Schuler A J, Hoon Jang. Density effects on activated sludge zone settling velocities. *Water Research* 2007; **41**: 1814-1822.

[9] Zhang D J, Li Z L, Lu P L, Zhang T, Xua D Y. A method for characterizing the complete settling process of activated sludge. *Water Res.* 2006; **40**,14: 2637-2644.

[10] Dauphin S, Joannis C, Deguin A, Bridoux G, Ruban G, Aumond M. Influent flow control to increase the pollution load treated during rainy periods.*Wat. Sci. Tech.* 1998; **37**, 12: 131-139.

[11] Joannis C, Aumond M, Dauphin S G, Ruban Deguin, A, Bridoux. Modeling activated sludge mass transfer in a treatment plant. *Wat. Sci. Tech.* 1999; **39**, 4:.29-36.

[12] Bürger R, Wendland W. Sedimentation and suspension flows: Historical perspective and some recent developments. *Journal of Engineering Mathematics* 2001; **41**:101-116.

[13] Chancelier J Ph, Cohen De Lara M, Joannis C, Pacard F. New insights in dynamic modelling of a secondary settler-I. Flux theory and steady-states analysis. *Wat. Res.* 1997; **31**, 8: 1847-1856.

[14] Chancelier J Ph, Cohen De Lara M, Joannis C, Pacard F. New insights in dynamic modelling of a secondary settler-II. Dynamical analysis. *Wat. Res.* 1997 ; **31**, 8:1857-1866.

[15] Bürger R, Concha F. Mathematical model and numerical simulation of the settling of flocculated suspensions. *International Journal of Multiphase Flow* 1998; **24**: 1005-1023.

[16] Sin G, Gernaey K V, Neumann M B, Mark C M, Van Loosdrecht M C M, Gujer W. Uncertainty analysis in WWTP model applications: A critical discussion using an example from design. *Water Research* 2009; **43**: 2894-2906.

[17] Vsilind P A. Theoretical considerations: design of prototype thickeners from batch settling tests. *Water Sewage Works* 1968; **115**, 7:302-307.